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The Vibration of the Raft-superstructure on the Saturated Soil under Moving Load by using a Semi-analysis Method

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Abstract

Based on Biot's theory and the minimum potential energy principle as well as the thin plate theory, the superstructure, raft and soil are assumed to be a whole system according to the substructure method. The system must satisfy the continuity conditions at the interface between the superstructure, raft and soil surface. Considering the compatibility condition that the vertical displacement of the interface between the raft and the saturated soil should be equal, the integral equation accounting for the vertical coupling of the superstructure-raft system with the saturated soil subjected to a moving load is constructed. Using the numerical inverse transform technique, the forces and displacements of the superstructure, plate and saturated soil at any time are obtained. Some numerical results are presented to demonstrate the capacity of the proposed model. Also, the influence of load velocity on the superstructure will be investigated in this paper.

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Keywords: Moving loads; saturated soil; superstructure; the thin plate theory; the substructure method; the integral equation

1. Introduction

To date, several analytical methods or semi-analytical methods are used to solve the dynamic response of foundation subjected to moving load. For example, Melrikine[1] studied vibration of a two-dimensional elastic layer generated by a point load moving uniformly along a beam by using the Fourier transform technique. Shadnam[2] studied the dynamic response of nonlinear thin plate under influence of relatively heavy moving masses by using the Banach's fixed point theorem. Celebi[3] used the thin layer method/flexible volume method (TLM/FVM) and the boundary element method to investigate the three-

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dimensional dynamic response of the free field nearby railway line induced by the moving load acting on the surface of a homogeneous or layered half-space.

The preceding review has primarily focused on the research work involving moving load in a single-phase elastic medium. However, many geotechnical engineering applications require multi-phase model of the soil. In fact, the growing body of literature suggested that under certain conditions there are significant differences in modeling the soil as a saturated poroelastic medium rather than a single-phase elastic medium. For saturated porous media, several scholars also have addressed the poroelastic medium subjected to a moving load. Theodorakopoulos[4] studied the dynamic response of a poroelastic half-space medium subjected to moving load by applying the Fourier series expansion. Jin[5] used the Fourier transform method to study stress and excess pore pressure induced in a saturated poroelastic half-space by moving line load. Lu[6] given an analytical solution for the dynamic response of a half-space porous medium subjected to a moving point load by using the Fourier transformation method. Hasheminejad[7] analyzed the steady-state axisymmetric dynamic response of an arbitrary thick elastic homogeneous cylinder of infinite length subjected to an axially moving ring load in a poroelastic soil.

It is worth mentioning that although many problems involving consolidation or dynamic response of poroelastic medium have been considered, the studies dealing with the application of Biot's theory for analysis of dynamic interaction between plate and structure under moving load are rather limited. The purpose of the present work is to investigate the dynamic interaction between plate and structure in a poroelastic half-space produced by moving load using a semi-analytical method. Biot's dynamic equations are solved by the Fourier transform technique.

2. Fredholm integral equations describing dynamic interaction between superstructure-raft and soil foundation due to a moving load

In this study, the dynamic responses of soil-raft-superstructure interaction system due to the passage of a vertical load are depicted in Fig. 1.

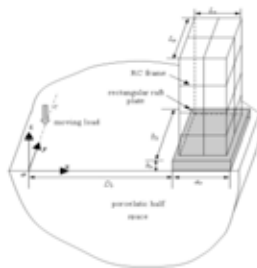


Fig. 1. Interaction between soil-raft-superstructure and a moving load on the surface of a poroelastic half-space

The superstructure is elastic multi-storey RC frame with a length L_x and a width L_y . The number of floor is N and the total high of layer is h . The rectangular raft plate is $a_r \times b_r$ with the thickness of plate h_r . The soil foundation is regarded as the poroelastic half-space. The load move with a constant speed c along the positive y -direction and the distance between the moving load track and the raft is D_s .

Superstructure is assumed as an elastic space frame. Then, using the finite element method, all of beams and poles are considered as space beam element with twelve DOF. The governing equations of the space beam element are given by:

$$[\mathbf{M}^e]\{\ddot{\delta}^e\} + [\mathbf{C}^e]\{\dot{\delta}^e\} + [\mathbf{K}^e]\{\delta^e\} = \{\mathbf{F}^e\} \quad (1)$$

where $\{\delta^e\}$, $\{\mathbf{F}^e\}$, $[\mathbf{M}^e]$, $[\mathbf{C}^e]$, $[\mathbf{K}^e]$ is the joint displacement, node force, mass matrix, damper matrix and element stiffness matrix of the space beam element, respectively.

In this work, a rectangular raft plate resting on a poroelastic medium is considered. The displacement can be expressed as

$$w_r(x, y, t) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} A_{mn}(t) \sin \frac{m\pi x}{a_r} \sin \frac{n\pi y}{b_r} + s(t) + x\phi_x(t) + y\phi_y(t) \quad (2)$$

where a_r , b_r are the length, width of the raft, respectively. $A_{mn}(t)$, $s(t)$, $\phi_x(t)$, $\phi_y(t)$ are unknown displacement parameters of the plate; $A_{mn}(t)$ is displacement of elastic deflection. $s(t)$, $\phi_x(t)$, $\phi_y(t)$ are the stiffness displacements of the raft

Using the minimum potential energy principle in the frequency domain, one has the following Fredholm integral equations describing dynamic interaction between superstructure-raft and soil foundation due to a moving load:

$$[\bar{C}_1]\{\bar{P}_b(\omega)\} + \frac{E_r h_r^3 a_r b_r}{48(1-\nu_r^2)} \left(\frac{m^2 \pi^2}{a_r^2} + \frac{n^2 \pi^2}{b_r^2} \right) \bar{A}_{mn}(\omega) + \int_D \bar{q}(X, \omega) \sin \frac{m\pi}{a_r} \sin \frac{n\pi}{b_r} d\Omega - \frac{1}{4} m_r \omega^2 \bar{A}_{mn}(\omega) = 0, \quad (3)$$

$$m = 1, 2, \dots, k; \quad n = 1, 2, \dots, k$$

$$[C_2]\{\bar{P}_b(\omega)\} + \int_D \bar{q}(X, \omega) d\Omega - m_r \omega^2 a_r b_r \bar{s}(\omega) = 0 \quad (4)$$

$$[C_3]\{\bar{P}_b(\omega)\} + \int_D \bar{q}(X, \omega) x d\Omega - \frac{1}{3} a^3 b m_r \omega^2 \bar{\phi}_x(\omega) = 0 \quad [C_4]\{\bar{P}_b(\omega)\} + \int_D \bar{q}(X, \omega) y d\Omega - \frac{1}{3} a b^3 m_r \omega^2 \bar{\phi}_y(\omega) = 0 \quad (5)$$

3. Numerical results and discussions

In this section, numerical examples will be used to demonstrate the capacity of the proposed model. The superstructure consists of steel reinforced concrete frame with twelve layers, the height of the storey is 3.0m, the length and width of each storey is $L_x \times L_y = 6.0 \text{ m} \times 12.0 \text{ m}$, the thickness of the floor is 100.0 mm, the beam plane is 250 mm \times 250 mm, the column plane is 400 mm \times 400 mm, the elastic modulus of the frame is $E_c = 3.0 \times 10^{10} \text{ Pa}$, the density of the frame is $\rho_c = 2.5 \times 10^3 \text{ Pa}$. The parameters of the raft are $a_r = 14.0 \text{ m}$, $b_r = 8.0 \text{ m}$, $h_r = 0.8 \text{ m}$, $E_r = 3.0 \times 10^{10} \text{ Pa}$, $\nu_r = 0.2$. The parameters of the poroelastic medium are $M = 2.4 \times 10^8 \text{ N/m}^2$, $\rho_s = 2.0 \times 10^3 \text{ kg/m}^3$, $\rho_f = 1.0 \times 10^3 \text{ kg/m}^3$, $\phi = 0.35$, $\alpha = 0.97$, $b_p = 1.94 \times 10^8 \text{ kg/m}^3 \text{ s}$, $a_\infty = 2.0$. The vertical distributed load moves parallel to the y-axis at a constant speed c and the direction of moving load is the negative of y-axis. The magnitude of the load is $F_z = 4.0 \times 10^5 \text{ kN/m}^2$ and it is uniformly distributed over a rectangle region $2a_s \times 2b_s = 0.8 \text{ m} \times 0.8 \text{ m}$. The distance between the load and the edge of the raft $D_s = 20.0 \text{ m}$. Fig. 2 shows that the horizontal displacements and vertical displacements of each floor of the superstructure increase with increasing the velocities of moving load.

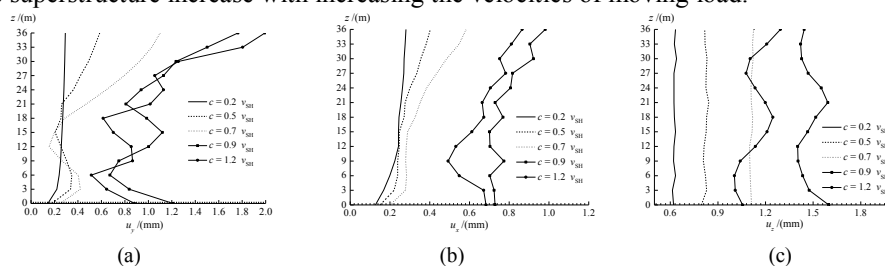


Fig. 2. Variation of the observer point with moving load velocity (a) the horizontal displacement u_y ; (b) the horizontal displacement u_x ; (c) the vertical displacement u_z

The vertical displacements in each floor have small change. The each floor of the building at the vertical direction likes a whole movement. When lower moving velocity ($c \leq 0.5 v_{SH}$), the curve of the horizontal displacements change smoothly with the superstructure height increasing. When higher

moving velocity ($c \geq 0.9 v_{SH}$), the curve of the horizontal displacements change obviously with superstructure height increasing. One can also see that a peak occurs near by the first layer when the moving load moves at a high speed ($c \geq 0.9 v_{SH}$). The main cause serious vibration in the lower layer is the high-frequency vibrating corresponding to the high speed moving load is declining rapidly with the increasing the superstructure height.

4. Conclusion

The integral transform method and substructure method are used to analyze the interaction of the poroelastic medium, plate and superstructure. The forces and displacements of the superstructure, plate and poroelastic medium at any time are obtained by using the numerical inverse transform technique. Based on the derivation and numerical examples presented above, the following conclusions are drawn: the horizontal displacements and vertical displacements of each floor of the superstructure increase with increasing the velocities of moving load. The vertical displacements in each floor have small change.

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